SOLAR THERMAL APPLICATION FOR NASA CENTERS

LANGLEY
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NASA CONTRACT NO. NAS1-14387
TASK ORDER NO. 25, PART A
FINAL REPORT

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PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HEADQUARTERS, MAINTENANCE AND OPERATIONS DIVISION
WASHINGTON, D.C. 20546

PREPARED BY
GRUMMAN AEROSPACE CORPORATION
ENERGY CONSERVATION SERVICES,
FACILITIES ENGINEERING DEPARTMENT
BETHPAGE, NEW YORK 11714

JULY 1978

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Solar Energy Studies

This task involves support to NASA Headquarters in solar thermal and solar voltaic projects. This interim report covers the solar thermal project, and by the NASA directive includes process heating and heating/cooling projects.

The initial thrust in project selection was to define systems that will be operational and provide a useful function. In addition, the project must be integrated into the rest of the buildings mechanical system in a cost effective manner. Solar savings are initially determined to obtain a fair comparision to other solar projects. At a later time, as the system integration is developed, applicable energy conservation savings can also be credited.

The project selection criteria by the Department of Energy is shown in the next figure. The first criteria is basically technical. This should be well suited to NASA, and some lead center such as LeRC or MSFC could be prime in evaluating and disseminating advancements to the other centers.

Market visibility criteria is good since most NASA centers have many visitors. The fuel cost portion of this criteria is not good when based on present NASA low fuel cost. If the solar program is to encourage private sector use of solar energy, it may be better to also consider the local commercial fuel cost in determining savings.

The last criteria is project cost and payback. Special cost that would not be incurred in future installations probably should not be included in the cost used to determine payback time. Therefore, there is a need to separate the costs attributed to unique design, retrofit, and special installation problems to encourage visibility. The payback based on total cost and present low fuel cost savings is not encouraging. Payback based on repeat construction and commercial fuel cost is much better.

U.S. DEPARTMENT OF ENERGY
SOLAR IN FEDERAL BUILDINGS PROGRAM

PROPOSAL EVALUATION CRITERIA

- INNOVATIVE AND DIVERSE SOLAR DESIGN APPLICATION
  - BUILDING TYPE
  - REPLICATION IN PRIVATE-SECTOR MARKET
  - BUILDING INTERFACE, COLLECTORS/STORAGE APPLICATION, CONTROL LOGIC
- PROJECT LOCATION (MARKETS)
  - ACCESSIBILITY AND VISIBILITY
  - PROXIMITY TO POPULATION CENTERS
  - INSOLATION/HEATING AND COOLING DEGREE-DAYS/FUEL COSTS
- PROJECT COSTS
  - TOTAL REQUEST
  - COST EFFECTIVENESS

This is an interim report listing proposed solar projects and was supplemented by an appendix under separate cover. This appendix includes NASA provided descriptions where available and as time permits. The format can permit updating and modifications as NASA requires. Some parametric data is provided at the end of the report for aid in early calculations.

Evaluation

Savings

The next table shows the solar energy savings at many NASA centers. As can be seen on the bottom line, the average savings at NASA is about $.60 per year per square foot of collector. One criteria for a good solar collector is one in which more money than the average is saved, while a poor location saves less than the average. A review of this table shows savings ranging from a low of $.25 to a high of $.96 per year per square foot.

Some poor locations are NSTL and MAF when low cost gas is saved by using solar collectors. Other poor locations are ARC and DFRC when a solar system replaces an electric driven air conditioning unit. A good location would be DFRC and ETS when higher cost oil or gas is saved by use of a solar system. An especially good application is a site with time of day electric demand charges. Future electric energy cost trends will result in many such locations. No example is included in this table since only average costs were determined. A study of each center's electric rate structure is required. At present KSC shows a savings of $.61 based on average electric cost, but this savings should approximately double when actual KSC demand cost is included.

Payback

Best payback times occur when high cost energy is supplemented by the solar system, and when fuel cost is inflating at a higher rate than the interest cost of money. Nominal cost of most of these projects is in the $100 per square foot range, with first year savings under $1 per square foot. Discounted escalated payback time is, therefore, over 35 years with the average fuel inflation 5% higher than the cost of money. Office of Management and Budget (OMB) criteria for payback analysis of energy conservation projects cannot be applied to the proposed solar energy projects and have them pay back within any conceivable

SOLAR ENERGY SAVINGS

		SOLAR INSULATION 10^3 BTU/YR. SQ. FT.	**$/YR. - SQ. FT.		
			ELEC. DRIVE SAVING COP = 3*	GAS SAVING COP = 1	OIL SAVING COP = 1
AMES	ARC	680	.25	.71	:74
DRYDEN	DFRC	751	.40	.75	.90
EDWARDS	ETS	751	.33	.96	---
GODDARD	GSFC				
JET PROP.	JPL	665	.71	.57	.50
JOHNSON	JSC				
KENNEDY	KSC	617	.61	---	.66
LANGLEY	LARC	598	.76	.66	.53
LEWIS	LERC	599	.53	.48	.90
MARSHALL	MSFC	564	.47	---	.64
MICHOUD	MAF	481	.47	.41	---
NATIONAL	NSTL	481	.46	.29	.52
ALL NASA		600	.54	.56	.62

* WHERE ELECTRIC DEMAND CHARGES APPLY, THESE SAVINGS CAN DOUBLE

** 36% SYSTEM EFFICIENCY - FY '78 1ST QUARTER ENERGY COST useful equipment lifetime.

NASA must define the method of payback analysis that is acceptable to DOE. In the interim, a method considered realistic is being utilized. An example of the importance of the payback criteria is shown at the end of the report as a maximum "Must Cost" solar system for 25-year payback time.

Technology

Some important engineering comparisions that can be obtained as the result of these projects are the relative payback and efficiency for:

(1) Advanced flat plate collectors with 1-stage absorption chillers

(2) Concentrating collectors with 2-stage absorption chillers

(3) Concentrating collectors with Rankine Cycle turbine drives

Only the latter two systems are capable of improved COP (efficiency) using the higher temperatures of concentrating collectors. The first system can profit to a lesser degree by eliminating the present chiller de-rating by using concentrating collectors. In addition, the control system logic can have a strong influence on savings. A good cross flow of control ideas and results between the NASA centers can greatly contribute to project success. One area where this contact would be especially useful is in dealing with the absorption chiller start-up problem. Presently, their long start-up periods must be repeated after sudden sustained drops of hot water supply temperature on some projects.

Project Performance Summary

The feasibility status of a proposed solar project can be followed on this table. The intent is to track the cost and savings of the project to ensure the NASA ground rules on payback are observed.

The first column represents reasonable values of efficiencies, savings and cost. After the project is defined by the NASA center personnel, a preliminary

PROJECT PERFORMANCE SUMMARY

	PRELIMINARY		DESIGN PHASE			TEST	
	ASSUMED	ESTIMATED	30%	80%	FINAL	PRELIMINARY	FINAL
COLLECTOR EFFICIENCY	45%						
STORAGE AND TRANSPORT EFFICIENCY	80%						
TOTAL SYSTEM EFFICIENCY	36%						
ANNUAL SAVINGS PER SQ. FT.	$.72						
TOTAL COST PER SQ. FT.	$100						
DESIGN PER SQ. FT.	$ 20						
CONSTRUCTION PER SQ. FT.	$ 80						
DEF = $\frac{\text{CONSTRUCTION COST}}{\text{SAVING}}$	111						
PAYBACK e = 8%, i = 3%	37 YRS.						
PAYBACK OMB e = 8%, i = 10%	NEVER PAYS						

design (1% design phase) estimate can be made. The output of this estimate is the start-off point for an A/E contract design phase. As the design phase continues, better values can be developed. This should help focus on the impurtant terms influencing payback time. Early test phases can provide verification or adjustment to the early analysis.

Savings, cost and payback analysis can be estimated from the figures at the end of this report. For preliminary analysis it is being assumed high performance collectors are used. Such collectors could have annual efficiencies as high as 45%. After collecting this energy it is assumed 20% is lost in all the lines, components and tanks, for a net storage efficiency of 80%. Therefore, the total solar system annual efficiency is assumed to be 36%.

If the solar system saves oil at a near future cost of $.40/gal. and is in an average solar location, the annual savings is $.72 per square foot. Total costs of high performance collector systems have been running about $100 per square foot of which $80 is the construction cost. Construction cost is used for the payback analysis. The discounted escalation factor (DEF) (explained in the Parametrics Section) is 111 years. This ratio of cost divided by savings is also sometimes referred to as simple payback time. For fuel oil inflating 8% faster than the general inflation, and money costing 3% higher than the general inflation, a payback time of 37 years is calculated.

For much higher cost of money, the project will never pay back. The Office of Management and Budget (OMB) directive to use the cost of money as 10% above the general inflation for energy conservation projects would eliminate most solar projects with present designs.

Projects for Process or Heating/Cooling

The following tables summarize a number of solar thermal projects submitted by the NASA centers. They are grouped as Phase 2 and Phase 3 for fiscal year 1978 and 1979 money, respectively. Phase 2 projects are further subdivided as 2A for projects funded for design and 2B as other potential projects for 1978 funds.

Payback time on these tables are based on all fuels inflating 10% per year higher than the interest rate applied to the cost of money. First year fuel cost savings due to the solar energy project are based on the present average NASA center utility cost. A few paybacks, such as shown for Phase 2A, were provided directly by NASA centers and possibly used different fuel inflation rates.

Charts are provided at the end of this report for economic evaluation of solar thermal systems. This information was used for cost and savings estimates to determine payback when information was not available from the NASA centers. DOE Facilities Solar Design Handbook information is utilized for system cost and annual available sunlight. Some charts allow use of different fuel inflation and interest rates.

The method of payback analysis varies greatly between all the people contacted. A consistant method should be established, and important considerations are discussed in this report. In the interim the above 10% net fuel inflation is utilized. It is suggested that in the interest of encouraging use of solar energy, a method compatible to commercial cost be used for payback analysis.

PROJECTS SUBMITTED BY NASA
FOR
SOLAR TECHNOLOGY APPLICATION

PHASE 2A+ FY '78

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	CONSTRUCTION COST $1000	TOTAL COST $1000	ESCALATED PAYBACK (YRS.) *	ANNUAL VISITORS	REMARKS
DFRC	Flight Loads Research Bldg. 4820	Heating & Cooling	4000	New Absorption Chiller - Hot & Chilled Water to Existing System	400	520	27	400,000	
KSC	Visitors Information Center (VIC) Bldg. M6-409	Heating & Cooling	4000	New 50 ton Absorption Chiller	440	570	23**	1,300,000	
MAF	Repro Facility Bldg. 320	Heating & Cooling	8000	New 50 ton Absorption Chiller	500	650	22	30,000	
MSFC	Medical Center Bldg. 4249	Heating & Cooling	2000	Rankine Cycle Modify Existing 25 ton Chiller	165	215	15***	800,000	
NSTL	Scientific Lab Bldg. 1105	Heating & Cooling	8500	New 75 ton Absorption Chiller	500	650	21	110,000	

TOTAL PHASE 2A = $2,605,000

\+ Design Funded

* Fuel Cost Escalated 10% per year above Interest Cost

** Payback based on Demand Rate

Payback - Based on solar savings.
- Energy Conservation savings can further decrease payback time.

*** Includes steam line loss savings

TOTAL COST INCLUDES
10% Contingency
10% Engineering Services
10% Design & Site Adaptation

PHASE 2B FY'78

PROJECTS SUBMITTED BY NASA
FOR
SOLAR TECHNOLOGY APPLICATION

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	CONSTRUCTION COST $1000	TOTAL COST. $1000	ESCALATED PAYBACK (YRS.) *	ANNUAL VISITORS	REMARKS
LaRC	Model Shop Bldg. 1236	Heating & Cooling	8000	Modify 218 ton Absorption Chiller	460	600	23	250,000	
	Employee Activities Facility Bldg. 1222	Heating & Cooling	6000	Rankine Cycle	450	585	25	250,000	
KSC	Landing Aids Control Bldg.	Heating & Cooling to supplement AHU#1 Load on Elec. Chiller	1200	New Absorption Chiller	200	260	27**	1,300,000	
	Bldg. K6-947 Utility Annex	Heating & Cooling to Supplement	10,000	New 100 ton Absorption Chiller	800	1040	20**	1,300,000	
NSTL	Central Control & Visitor Center Bldg. 1200	Heating & Cooling	5000	Modification of 2 Absorption Chillers of 225 ton	405	530	24	110,000	
	Shuttle Engine Checkout & Test Facility Bldg. 3202	Heating & Cooling	3400	New 25 ton Absorption Chillers	350	455	27	110,000	

TOTAL PHASE 2B = $ 3,470,000

TOTAL 2A + 2B = $ 6,075,000

* Fuel Cost Escalated 10% per year above Interest Cost

** Payback based on Demand Rate

Payback - Based on solar savings.
- Energy Conservation savings can further decrease payback time.

PROJECTS SUBMITTED BY NASA FOR SOLAR TECHNOLOGY APPLICATION

PHASE 3 FY'79

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	CONSTRUCTION COST $1000	TOTAL COST. $1000	ESCALATED PAYBACK (YRS.) *	ANNUAL VISITORS	REMARKS
DFRC	Laboratory Bldg. 4800, 1963 Extension	Heating & Cooling to Supplement Gas	6000	Modify Existing 150 Ton Absorption Chiller	580	755	27	400,000	
	Integrated Support Facil. Bldg. 4825	Heating & Cooling to Supplement Elec. DX Chillers	7000	New Absorption Chiller	665	865	27	400,000	
KSC	New "Press Site"	Heating & Cooling to Supplement One Elec. Chiller(CU#1)	1750	New Absorption Chiller	175	230	22**	1,300,000	
LaRC	CMTA Area by Photo Lab	Area Process Heating & Some Supplement to Cooling	8000	Supplement Central Heating that Supplies Existing Systems	460	600	23	250,000	
	Headquarters Bldg. 1219	Heating & Cooling	600	2 New 3 Ton Absorption Chillers	100	130	33	250,000	

* Fuel Cost Escalated 10% per year above Interest Cost

** Payback based on Demand Rate

Payback - Based on solar savings.
- Energy Conservation savings can further decrease payback time.

PROJECTS SUBMITTED BY NASA
FOR
SOLAR TECHNOLOGY APPLICATION

PHASE 3 FY'79

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	CONSTRUCTION COST $1000	TOTAL COST. $1000	ESCALATED PAYBACK (YRS.) *	ANNUAL VISITORS	REMARKS
ARC	Bldg. 236 Animal Facility	Process Water to Supplement Gas Heating	5000	Provide 180°F for Cage Washing	250	325	21	130,000	
	Space Sciences Office Bldg.	Heating & Cooling	1200	New Absorption Chiller	130	170	28	130,000	
JPL	Edwards Test Station Bldg. E40,41,75	Process Heating to Supplement Elec. Heat.	1000	Provide 150°F Cell Environment for Solid Propellant Processing Area	145	190	28	400,000	
	JPL Visitor Control	Heating & Cooling Plus Electric Generator	2800	Rankine Cycle Elec. Drive and Absorption Chiller	540	705	31	55,000	
	Bldg. 138 Mission Operation Bldg.	Heating & Cooling	4800	New Absorption	380	480	22	55,000	

* Fuel Cost Escalated 10% per year above Interest Cost

Payback - Based on solar savings.
- Energy conservation savings can further decrease payback time.

PROJECTS SUBMITTED BY NASA
FOR
SOLAR TECHNOLOGY APPLICATION

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	TOTAL COST. DESIGN AND CONSTRUCTION	DEF = COST / 1ST YR SVGS	PAYBACK (YRS.) *	RECOMMENDED PRIORITY	REMARKS
MAF	Stage Test Position Facil., Bldg. 420	Supplement Gas for Heating and Cooling of Control Bldg.	10,000	New 100 ton Absorption Chiller	800	1040	24	30,000	Reduces the Chiller Water Flow from Central Boiler Plant
MAF	Office & Engi-neering Bldg. 350	Supplement Gas For Heating & Cooling of Central Wing of Building	10,000	New 100 Ton Absorption Chiller	800	1040	24	30,000	Computer Facility Runs Around the Clock
MSFC	Calibration Lab Bldg. 4471	Supplement Elec. and Steam for Heating and Cooling	5,000	New 50 Ton Absorption Chiller	395	515	11**	800,000	Calibration Lab Operates 24 Hrs./Day Good Payback
MSFC	Communications Bldg. 4207	Supplement Elec. and Steam for Heating and Cooling	8,000	New 200 Ton Absorption Chiller	700	910	15**	800,000	Comm. Bldg. Operates 24 Hrs./Day Good Payback
NSTL	South Reception Center, Bldg. 3101	Supplement Electric Heat Pump Heating & Cooling	2,000	New 20 Ton Absorption Chiller	180	260	25	110,000	Used 7 Days per Week. Elec. Heating & Cooling should give good payback

* Fuel Cost Escalated 10% per Year above Interest Cost

** Includes steam line loss savings

Payback - based on solar savings.
- energy conservation savings can further decrease payback time

PROJECTS SUBMITTED BY NASA
FOR
SOLAR TECHNOLOGY APPLICATION

CENTER	PROJECT	APPLICATION	SOLAR COLLECTORS (SQ. FT.)	METHOD OF HEATING/COOLING	TOTAL COST. DESIGN AND CONSTRUCTION	DEF = COST / 1ST YR SVGS	PAYBACK (YRS.) *	RECOMMENDED PRIORITY	REMARKS
NSTL	Acoustics (New Computer Center) Bldg. 1110	Supplement Gas for Heating & Cooling	5,000	New 50 Ton Absorption Chiller	450	665	25	110,000	Computer Center requires 24 Hrs./Day Temp. Control Good Payback.

TOTAL PHASE 3 $ 8,880,000

* Fuel Cost Escalated 10% per year above Interest Cost

Payback - Based on solar savings.
- Energy Conservation savings can further decrease payback time.

Parametric Analysis

This section provides information for the approximate economic evaluation of a solar thermal system providing either process heating or a heating/cooling system. The following information is included:

- o NASA energy cost
- o Energy real growth rate
- o Commercial electric cost
- o Annual savings by solar thermal system
- o Cost of solar thermal systems
- o Discounted escalation payback time
- o Discounted escalation factor
- o "Must Cost" estimate for solar systems

NASA Energy Cost

This table shows the actual NASA energy cost for the last three months of 1977. In a few cases present gas costs are escalated to 1982 rates, and used as indicated. These values are being used for estimates of first year energy savings produced by a solar energy system. In general, the higher the energy charge, the higher the savings. This does not favor Ames or Dryden electric savings.

The most important factor in savings from a solar energy system is the cost of the fuel source that is saved. Fuel cost is followed in importance by system efficiency and of minor relative importance is the amount of sunlight received. A small error results from failure to escalate all the fuel cost to operation starting time (10 - 20% increase). The exceptionally low gas prices were escalated.

The largest error in using this table involves the electric cost, which is also 2/3 of all NASA energy cost. The error comes about by not accounting for energy charge and demand charge separately. Electric power is saved in the afternoons of summer days by a solar air conditioning or photovoltaic system. It should be determined if an electric demand charge is saved. Some NASA centers have a daytime peak electric demand and dollar charge. In addition, the peak demand is coincided with peak air conditioning requirements. Under such conditions total savings can possibly double with a solar system.

Centers with large research power demands, such as Ames (ARC), Langley (LaRC) and Lewis (LeRC), are poor candidates to take advantage of the demand savings possible with solar systems. To save operating cost the research centers have a tendency to operate the research power systems at the "off peak" time-of-day. As a result, their average cost of energy is lower. A center such as KSC seems to be a good candidate for peak demand savings since its energy damend can be air conditioning dependent. The exception to this is the KSC launch impact, and has not been examined here.

NASA ENERGY COST AND SOLAR SAVINGS
FOR FIRST QUARTER FY '78

* WHERE ELEC. DEMAND IS APPLICABLE, THESE SAVING CAN DOUBLE

**SOLAR SYSTEM EFFICIENCY = 36%

( ) ESTIMATED GAS RATES FOR 1982.

		ELEC. $/KWH	GAS $/1000 CU. FT.	OIL $/GAL.	ALL OTHER UTILITIES	DOE HANDBOOK SOLAR INSOLATION 10^3 BTU/ft^2	**SAVINGS $/YR. SQ. FT. ELEC. DRIVE SAVINGS* COP = 3	GAS SAVINGS N=80% COP = 1	OIL SAVINGS N=80% COP = 1
AMES	ARC	.0105	2.3795	.3636		680	$.25/yr ft^2	$.71/	$.74/yr ft^2
DOWNEY	DWN	.0300	2.0675	----					
DRYDEN	DFRC	.0153	2.2719	.4000		751	.40	.75	.90
EDWARDS	ETS	.0125	2.9197	----		"	.33	.96	--
GODDARD	GSFC	.0337	2.3668	.3950					
JPL	JPL	.0303	1.9704 (2.80)	.2500		665	.71	.57 (1.00)	.50
JOHNSON	JSC	.0194	2.6776	.3571					
KENNEDY	KSC	.0279	------	.3563		617	.61	---	.66
LANGLEY	LARC	.0348	2.5063	.2971		598	.73	.66	.53
LEWIS	LERC	.0250	1.8159	.5000		599	.53	.48	.90
MARSHALL	MSFC	.0238	------	.3762		564	.47	---	.64
MICHOUD	MAF	.0277	1.9315 (2.80)	----		481	.47	.41 (0.80)	---
NATIONAL	NSTL	.0271	1.3954 (2.80)	.3636		481	.46	.29 (0.80)	.52
PLUM	PBS	.0285	2.1708	1.00					
SANTA SUSANA	SS	.0377	2.1738	----					
SLIDELL	SCC	.0267	2.0291	----					
TRACKING	UTDA	.0353	------	.3956					
WALLOPS	WFC	.0307	------	.3566					
WHITE SANDS	WSTF	.0285	2.5336	----					
ALL NASA		.0256	2.1428	.3449	$4.13/10^6 BTU	600	$ .54/yr ft^2	$ .56/yr ft^2	$ .62/yr ft^2
% OF NASA TOTAL ENERGY		68%	15%	7%	4% = 93%				

Energy Real Growth Rate

DOE has provided this table to be used on a temporary basis as a representation of fuel inflation rate. The growth rate is presented as an annual percentage in addition to the general inflation.

This chart is a great simplification. Within any region, the cost varies. The very low cost systems will inflate at a faster rate than the high cost systems. The local price structure and growth rate should be used when known. Low cost electric energy from hydroelectric plants, especially the Bureau of Reclamation, will have the most dramatic increase in cost and rate structure.

ANNUAL ENERGY REAL GROWTH RATES
FOR LIFE-CYCLE COSTING

Coal	5%
Fuel Oil	8%
Gas (Natural or LPG)	10%

ELECTRICITY

Region	Region
New England - 6.9%	East North Central - 5.6%
Middle Atlantic - 5.9%	West North Central - 5.6%
South Atlantic - 5.8%	West South Central - 7.5%
East South Central - 5.6%	Mountain - 5.7%
Pacific - 7.3%	

Ref. - DOE Facilities, Solar Design Handbook

Commercial Electric Rates

In contrast to the NASA electric rates, this table shows the commercial electric rates. This table runs from a low of 1.438 ¢/KWH to a high of 8.45 ¢/KWH in December of 1977. The primary difference is the lower NASA rates at some centers due to special discounts or use of Bureau of Reclamation energy. The low energy cost makes energy conservation projects difficult to sell and makes solar energy projects unrealistic. Through governmental action future trends will be to eliminate these discounts.

It has been suggested that the NASA projects payback time be evaluated based on the local utility rates. The justification for this is the desire to use the government projects as demonstrations to encourage local communities to use solar energy.

Of the 80 cities represented, 10 show rates down by one percent or better from the year-earlier month. In the table for November, only 9 were down.

Monthly bill to a commercial customer using a hypothetical 10,000 kwh at a maximum volume of 40 kw.

State and City	Dec. 1977	Dec. 1976	% Chg.	Utility
ALABAMA:				
Birmingham	$430.56	$411.68	+5	Alabama Power Co.
Huntsville	273.91	246.30	+11	Public agency
ARIZONA:				
Phoenix	468.20	382.40	+22	Public agency
ARKANSAS:				
Little Rock	415.00	358.19	+16	Arkansas Power & Light
CALIFORNIA:				
Long Beach	438.60	388.00	+13	South Calif. Edison
Los Angeles	467.33	397.63	+18	Municipality
Sacramento	194.15	194.15	0	Public agency
San Francisco	553.50	370.10	+50	Pacific Gas & Elec.
COLORADO:				
Colorado Springs	318.77	273.59	+17	Municipality
Denver	383.20	366.73	+4	Public Service Co.
CONNECTICUT:				
Bridgeport	527.74	499.94	+6	United Illuminating Co.
Groton	445.79	460.92	−3	Municipality
Hartford	584.74	510.75	+14	Hartford Elec. Light Co.
Wallingford	471.80	478.49	−1	Municipality
Waterbury	524.90	502.80	+4	Conn. Light & Power Co.
FLORIDA:				
Jacksonville	486.75	440.25	+11	Public agency
Lakeland	431.45	469.25	−8	Municipality
Miami	505.11	448.75	+13	Fla. Power & Light Co.
Orlando	364.10	449.93	−19	Municipality
GEORGIA:				
Atlanta	499.11	493.97	+1	Georgia Power Co.
IDAHO:				
Boise	265.55	240.75	+10	Idaho Power Co.
ILLINOIS:				
Chicago	525.70	476.49	+10	Commonwealth Edison Co.
Springfield	468.08	468.08	0	Municipality
INDIANA:				
Anderson	447.67	414.77	+8	Public agency
Fort Wayne	377.63	299.11	+26	Indiana-Mich. Electric
Richmond	393.67	379.27	+4	Public agency
KANSAS:				
Kansas City	424.01	403.31	+5	Municipality
Wichita	487.35	387.65	+26	Kansas Gas & Elec. Co.
KENTUCKY:				
Louisville	329.37	279.44	+18	Louisville Gas & Elec. Co.
LOUISIANA:				
New Orleans	255.04	245.44	+4	La. Power & Light Co.
MAINE:				
Portland	367.35	343.35	+7	Central Maine Power Co.
MASSACHUSETTS:				
Boston	621.26	530.31	+17	Boston Edison Co.
Chicopee	421.93	378.02	+12	Municipality
Reading	641.86	495.53	+30	Municipality
Taunton	651.49	557.23	+17	Municipality
Worcester	538.40	498.90	+8	Massachusetts Elec. Co.
MICHIGAN:				
Detroit	479.70	464.42	+3	Detroit Edison Co.
Flint	501.70	484.90	+3	Consumers Power Co.
Lansing	398.62	376.92	+6	Municipality
MINNESOTA:				
Minneapolis	399.33	324.97	+23	Northern States Power Co.
Rochester	364.10	378.70	−4	Municipality
MISSISSIPPI:				
Jackson	$461.55	$447.40	+3	Miss. Power & Light Co.
MISSOURI:				
Independence	432.40	385.90	+12	Municipality
Kansas City	505.73	479.92	+5	Kans. City Power & Light Co.
St. Louis	448.49	449.53	0	Union Electric Co.
NEBRASKA:				
Omaha	311.85	325.55	−4	Municipality
NEW JERSEY:				
Newark	631.20	591.32	+7	Public Service Electric
Vineland	592.47	575.88	+1	Municipality
NEW YORK:				
Buffalo	457.22	423.73	+8	Niagara Mohawk Power Co.
Jamestown	333.57	318.07	+5	Municipality
New York	845.52	830.84	+2	Consolidated Edison Co.
Plattsburgh	143.80	125.25	+15	Municipality
Rockville Center	476.25	402.25	+18	Municipality
NORTH CAROLINA:				
Charlotte	396.66	347.06	+14	Duke Power Co.
OHIO:				
Canton	401.00	389.96	+5	Ohio Power Co.
Cleveland	483.64	464.65	+4	Cleveland Electric Co.
Cleveland	459.10	397.93	+15	Municipality
Youngstown	484.95	375.98	+29	Ohio Edison Co.
OKLAHOMA:				
Oklahoma City	334.35	345.43	−3	Okla. Gas & Elec. Co.
Vinita	398.60	267.10	+49	Public agency
OREGON:				
Portland	231.55	208.81	+11	Pacific Power & Light Co.
PENNSYLVANIA:				
Philadelphia	552.33	528.03	+5	Philadelphia Electric Co.
Scranton	482.92	464.84	+4	Pa. Power & Light Co.
SOUTH CAROLINA:				
Conway	269.25	217.95	+24	Public agency
TENNESSEE:				
Chattanooga	301.05	272.00	+11	Municipality
Memphis	287.30	266.30	+8	Municipality
TEXAS:				
Austin	488.87	498.17	−2	Municipality
Fort Worth	340.21	297.91	+14	Texas Elec. Service Co.
Houston	326.20	312.52	+4	Houston Lighting & P. Co.
San Antonio	446.07	454.54	−2	Municipality
Waco	439.92	386.81	+14	Texas Power & Light Co.
UTAH				
Salt Lake City	503.85	419.63	+20	Utah Power & Light Co.
VERMONT:				
Burlington	324.40	325.50	0	Municipality
VIRGINIA:				
Arlington	476.34	412.62	+15	Va. Electric & Power Co.
WASHINGTON:				
Seattle	162.83	147.09	+11	Municipality
Tacoma	164.15	164.15	0	Municipality
WEST VIRGINIA:				
Charlestown	368.60	368.60	0	Appalachian Power Co.
WISCONSIN:				
Kaukauna	257.92	271.92	−5	Public agency
Manitowoc	350.66	360.17	+17	Public agency
Milwaukee	377.39	366.39	+3	Wisconsin Elec. Power Co.

Source: Federal Energy Regulatory Commission data collected for use by Bureau of Labor Statistics.

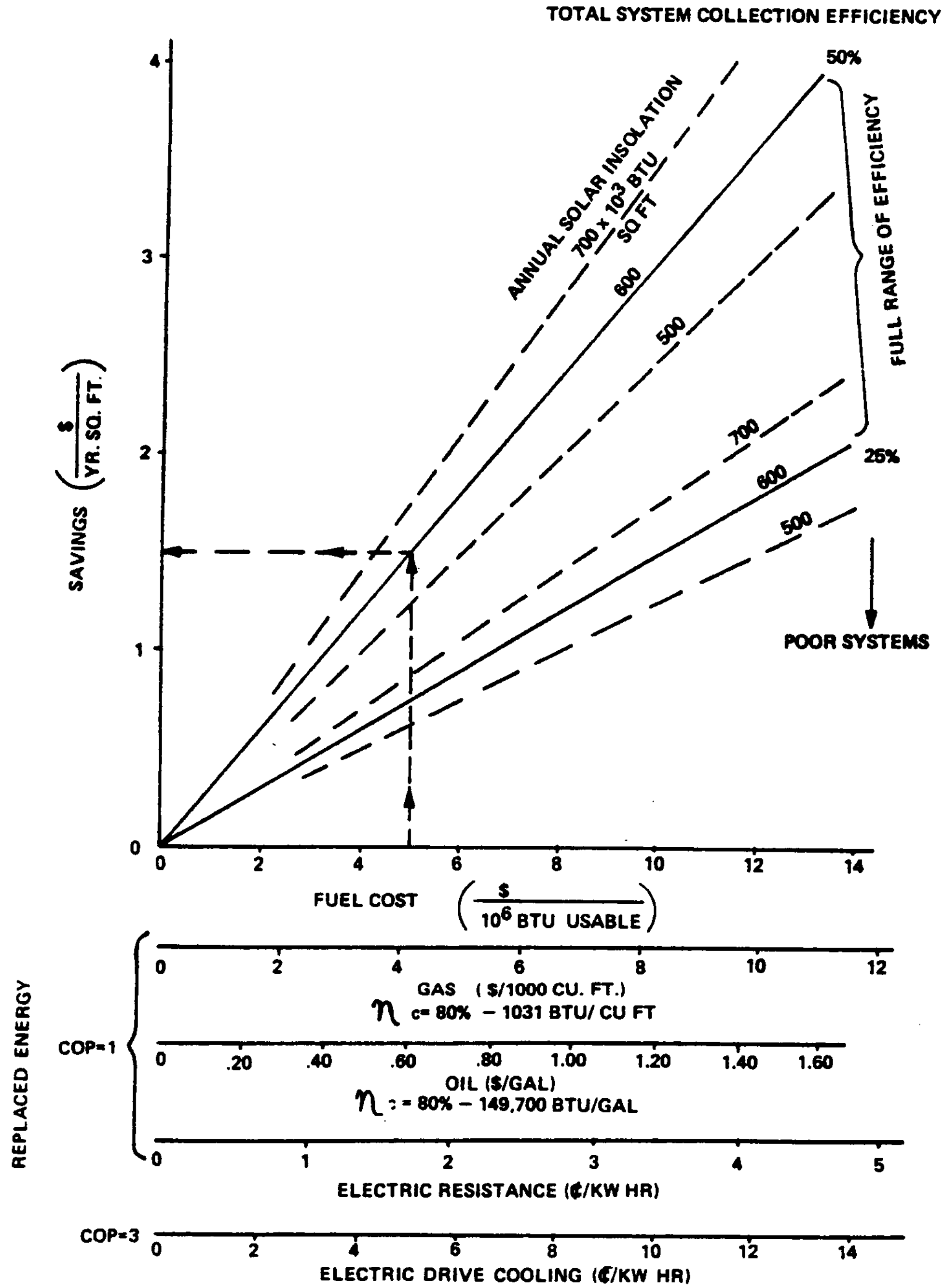
Annual Savings By Solar Thermal System

This figure gives an estimate of the dollar value of the thermal energy produced by a solar collector system. This is a rapid way to obtain the range of possible savings and is not a substitute for a more detailed analysis, which must show how the daily absorbed solar energy is utilized. The following assumes there is always need for the absorbed energy.

An example is shown with savings of $1.50 per year for each sq. ft. of collector surface. The sample problem is to find the savings if fuel oil at $.60 per gallon is presently used. A good combustion system at 80% efficiency would produce usable energy at $5 per million BTU. The typical annual solar energy falling on a panel will be about 600,000 BTU per square foot. Of this energy, 50% collected and finally delivered as usable energy is representative of the high end of the total system annual collection efficiency. This combination of terms then results in an annual fuel oil savings of $1.50 per square foot.

The advantage of this simplistic figure is that it emphasizes three factors: fuel cost, system efficiency, and available solar energy. The prime factor is the cost of the fuel that is replaced by solar energy. The second factor is the total system collection efficiency. This represents the fraction of solar energy that is absorbed by the collector, and is finally delivered as heat after all system losses are accounted for. This is the only factor within the control of the designer, but is still expected to fall within some reasonable range as indicated. It is difficult to achieve an efficiency over 50%, while much under 25% is a poor system. The third factor, available solar radiation, is actually a narrow range. The majority of the USA falls within the indicated range when collectors are inclined within 10° of the local latitude.

SOLAR THERMAL SYSTEM ANNUAL SAVING



If this simplified savings estimate indicates sufficient dollar savings, then a more detailed analysis can be justified. The next level of detail analysis is aimed at determining the collector efficiency and the storage and distribution efficiency (losses determined) to meet the temperature requirement of the particular application.

SOLAR SYSTEM COST ESTIMATES FOR COMMERCIAL BUILDINGS [1]

A. Subsystem Costs	Fraction of Total Solar Cost
1. Collectors and supports	35%
2. Storage and heat exchangers	20%
3. Piping, controls, electrical, and installation	45%

B. Component Costs	Cost/SF_c
1. Collectors	\$5.00 - 20.00
a. Nonselective	\$5.00 - 10.00
b. Selective	\$10.00 - 20.00
c. Collector support structure	\$3.00 - 10.00
2. Heat exchangers	\$0.40 - 0.80
3. Collector fluid	\$0.15 - 0.20
4. Storage tank and insulation	\$2.00 - 5.00
5. Piping, insulation, expansion tanks, valves	\$3.00 - 6.00
6. Pumps	\$0.40 - 1.00
7. Controls and electrical \$3,000 - 5,000	

C. Systems Costs by Type	Installed Cost/SF_c		Total Cost/SF_c	
	New	Retrofit	New	Retrofit
1. BSHW only	\$20 - 35	\$22 - 44		
2. Space and BSHW heating	\$25 - 50	\$28 - 63		
3. Space heating and cooling	\$35 - 65	\$39 - 81	\$44-81	\$49 - 101

[1] Ref. - DOE Facilities Solar Design Handbook

Solar Thermal System Capital Costs [1]

In estimating the capital cost of solar system components, only the costs of items that are not normally part of a conventional HVAC system should be considered. Thus, the cost of the building's air-handling system would not be considered, but the difference between the installed cost of a more expensive absorption chiller and of a less expensive centrifugal chiller should be charged to the solar energy system. Note that certain cost elements vary according to the size of a solar heating and/or cooling system whereas others are relatively fixed, regardless of collector area or tank volume. Collector and storage tank costs are system-size-dependent items; others include heat exchanger costs, and certain pump and piping costs. The additional control system cost associated with a solar energy system is an example of a cost difference that is largely independent of collector area. The cost difference associated with the purchase and installation of an absorption chiller is also relatively independent of solar collector area, because for all but the smallest solar collector areas, selection of an appropriate absorber is dictated by the peak building-cooling load.

Because solar system costs depend on the purchaser's location and are also time-dependent, the designer should obtain actual price quotes from equipment manufacturers. However, for initial assessments, costs can be estimated from the data given in this table.

The subsystems to be considered are shown along with an estimate of the fraction of the total installed cost that each requires. If solar cooling is included, the incremental costs of a derated chiller and/or cooling tower are in addition to those listed.

Part B of this table summarizes estimated solar system component costs. In lieu of actual manufacturer-quoted prices, these may be used as first estimates.

In addition, the differential cost of a derated absorption chiller, compared to a standard compression unit that probably would be used in a conventional system, is about $100-120/ton. One also must include solar-energy related costs such as those resulting from increased floor space required to accommodate solar equipment. Credit should be given for any roof area provided by roof-integral collectors. Remember, moreover, that collectors must be mounted on some sort of structure. When all expenses are included, the installed system costs shown in Part C result.

Recent experience indicates that the installed incremental system costs in part C, would be expected for new construction; 10-25% more should be expected for retrofit construction.

Total project cost will be higher by about 25% to cover cost of design, inspection, and contingency.

[1]Ref. - DOE Facilities Solar Design Handbook

DISCOUNTED ESCALATION PAYBACK TIME

The payback time is being determined on a present worth basis. When the present worth of the annual fuel savings has added up to the installation cost, the system has paid for itself. Several other factors of maintenance, taxes, insurance and collector useful life can be factored in after a simplified evaluation indicates it is feasible to continue. These other factors can be fixed percentages added to the interest rate.

This figure can be used to determine payback time after determining the system cost divided by the first year's fuel savings. This ratio is called the Discounted Escalation Factor (DEF) and is equal to simple payback time when no fuel cost growth or interest on money is considered. When fuel cost increases and cost of money is included the payback time can be shorter or longer than the simple payback time. If fuel is inflating faster than the cost of money, then payback time is shorter than simple payback. If the cost of money is greater than fuel inflation, then longer than simple payback time occurs.

$$\text{Future cost of fuel in one specific year} = \text{Present fuel cost} \times (1 + e + g)^n$$

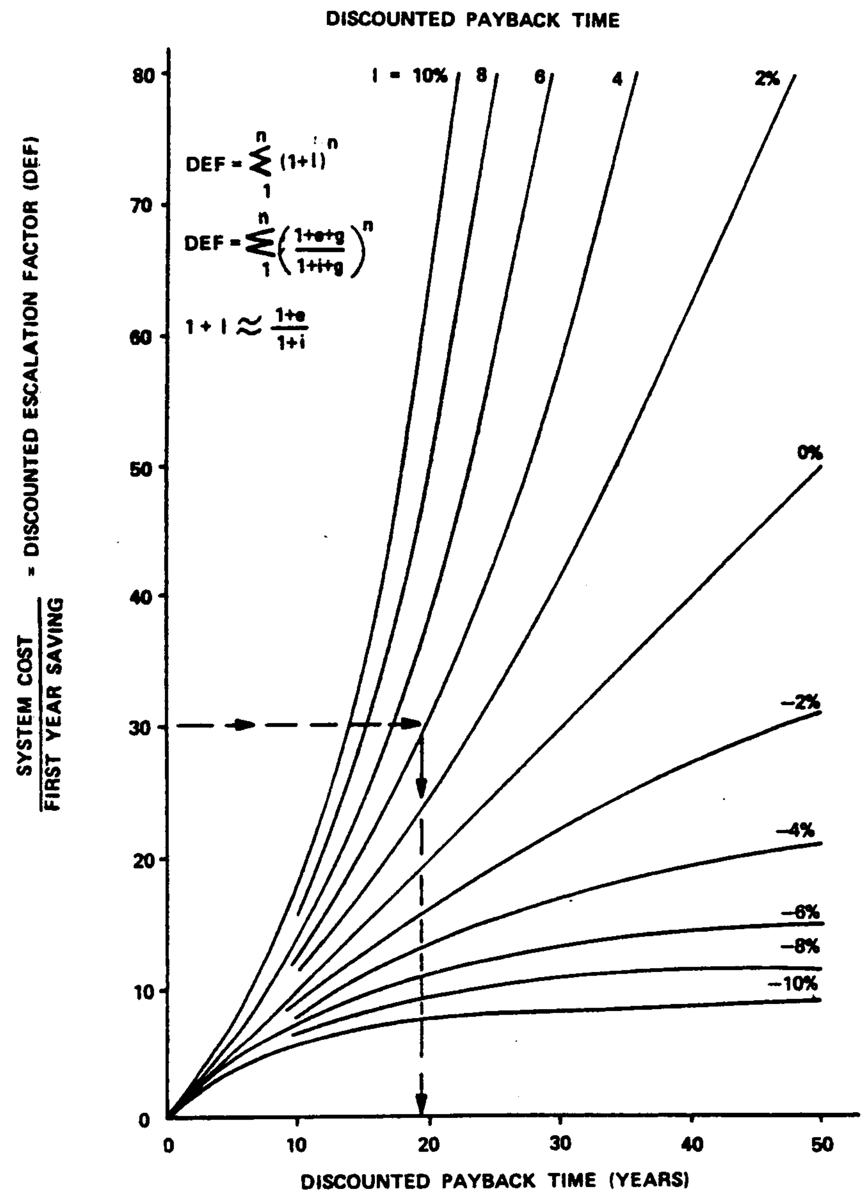
g = General Inflation $\frac{\%}{100}$

e = Energy growth rate over general inflation $\frac{\%}{100}$

n = years

$$\text{(Present worth of Future fuel) in one specific year} = \text{Future Cost of Fuel} \times \left(\frac{1}{1 + i + g}\right)^n$$

i = Cost of money over general inflation $\frac{\%}{100}$


DISCOUNTED PAYBACK TIME
I = 10%
8
6
4
2%
0%
−2%
−4%
−6%
−8%
−10%
DEF = $\sum_{1}^{n} (1+I)^{n}$
DEF = $\sum_{1}^{n} \left(\frac{1+e+g}{1+i+g}\right)^{n}$
$1 + I \approx \frac{1+e}{1+i}$
SYSTEM COST / FIRST YEAR SAVING = DISCOUNTED ESCALATION FACTOR (DEF)
DISCOUNTED PAYBACK TIME (YEARS)
0
10
20
30
40
50
60
70
80

In a step wise manner, the cumulative present worth is determined as a product of these two factors:

$$\text{Total Present Worth} = \begin{array}{l}\text{Present Fuel}\\ \text{Cost}\end{array} \sum_{i}^{n} (1+e+g)^{n} \times \left(\frac{1}{1+i+g} \right)^{n}$$

$$= \begin{array}{l}\text{Present Fuel}\\ \text{Cost}\end{array} \sum_{i}^{n} \left(\frac{1+e+g}{1+i+g} \right)^{n}$$

The term $\sum_{i}^{n}\left(\frac{1+e+g}{1+i+g}\right)^{n}$ is called the discounted escalating factor (DEF).

A simplification would be equating all the % values to an equivalent fuel inflation value:

$$1 + I = \frac{1 + e + g}{1 + i + g} \approx \frac{1 + e}{1 + i}$$

A further approximation would be obtained by dropping the general inflation term. The value "I" can be positive or negative.

EXAMPLE:

The DOE Solar Design Handbook (pg. 60) suggests an 8% discount rate be used to correspond to long term U.S. Treasury Bonds. That 8% is the summation of i + g. If g is assumed as 5% on a long term basis, then i = 3%. Fuel oil is inflating 8% (e = .08) per DOE handbook. Therefore, the equivalent fuel inflation value I is determined as follows:

$$1 + I = \frac{1 + .08 + .05}{1 + .08} = 1.046$$

$$1 + I \approx \frac{1 + .08}{1 + .03} = 1.0485 \qquad I \approx (e+g) - (i+g) = 13\% - 8\% = 5\%$$

Therefore, I = 5%

DISCOUNTED ESCALATION FACTOR (DEF)

This is a tabular form of the previous figure and is used as follows:

1) Determine the equivalent fuel inflation ($I \approx e - i$) by subtracting cost of money in excess of inflation from energy growth rate in excess of inflation.

2) Determine the DEF (System Cost/First year Saving)

3) Read down the equivalent fuel inflation column to the value of DEF and then over to the number of years to pay back.

DISCOUNTED ESCALATION FACTOR (DEF)

SUM OF CAF - (1+I)**N

YEARS	-10%	-8%	-6%	-4%	-2%	0%	2%	4%	6%	8%	10%
1	0.900	0.920	0.940	0.960	0.980	1.000	1.020	1.040	1.060	1.080	1.100
2	1.710	1.766	1.824	1.882	1.940	2.000	2.060	2.122	2.184	2.246	2.310
3	2.439	2.545	2.654	2.766	2.882	3.000	3.122	3.246	3.375	3.506	3.641
4	3.095	3.261	3.435	3.616	3.804	4.000	4.204	4.416	4.637	4.867	5.105
5	3.686	3.921	4.169	4.431	4.708	5.000	5.308	5.633	5.975	6.336	6.716
6	4.217	4.527	4.859	5.214	5.594	6.000	6.434	6.898	7.394	7.923	8.487
7	4.695	5.085	5.507	5.965	6.462	7.000	7.583	8.214	8.897	9.637	10.436
8	5.126	5.598	6.117	6.687	7.313	8.000	8.755	9.583	10.491	11.488	12.579
9	5.513	6.070	6.690	7.379	8.146	9.000	9.950	11.006	12.181	13.487	14.937
10	5.862	6.505	7.228	8.044	8.963	10.000	11.169	12.486	13.972	15.645	17.531
11	6.176	6.904	7.735	8.682	9.764	11.000	12.412	14.026	15.870	17.977	20.384
12	6.458	7.272	8.211	9.295	10.549	12.000	13.680	15.627	17.882	20.495	23.523
13	6.712	7.610	8.658	9.883	11.318	13.000	14.974	17.292	20.015	23.215	26.975
14	6.941	7.921	9.078	10.448	12.072	14.000	16.293	19.023	22.276	26.152	30.772
15	7.147	8.208	9.474	10.990	12.810	15.000	17.639	20.824	24.672	29.324	34.949
16	7.332	8.471	9.845	11.510	13.534	16.000	19.012	22.697	27.213	32.750	39.544
17	7.499	8.713	10.195	12.010	14.243	17.000	20.412	24.645	29.905	36.450	44.599
18	7.649	8.936	10.523	12.490	14.938	18.000	21.840	26.671	32.760	40.446	50.158
19	7.784	9.141	10.832	12.950	15.620	19.000	23.297	28.778	35.785	44.762	56.274
20	7.906	9.330	11.122	13.392	16.287	20.000	24.783	30.969	38.992	49.422	63.002
21	8.015	9.504	11.394	13.816	16.941	21.000	26.299	33.248	42.392	54.456	70.402
22	8.114	9.663	11.651	14.224	17.583	22.000	27.845	35.618	45.995	59.893	78.542
23	8.202	9.810	11.892	14.615	18.211	23.000	29.421	38.082	49.815	65.764	87.496
24	8.282	9.945	12.118	14.990	18.827	24.000	31.030	40.645	53.864	72.105	97.346
25	8.354	10.070	12.331	15.350	19.430	25.000	32.670	43.311	58.155	78.954	108.180
26	8.418	10.184	12.531	15.696	20.022	26.000	34.344	46.084	62.705	86.350	120.098
27	8.477	10.289	12.719	16.029	20.601	27.000	36.051	48.967	67.527	94.338	133.208
28	8.529	10.386	12.896	16.347	21.169	28.000	37.792	51.966	72.638	102.965	147.628
29	8.576	10.475	13.062	16.654	21.726	29.000	39.567	55.084	78.057	112.282	163.491
30	8.618	10.557	13.219	16.947	22.271	30.000	41.379	58.328	83.800	122.344	180.940
31	8.657	10.633	13.366	17.229	22.806	31.000	43.226	61.701	89.888	133.212	200.134
32	8.691	10.702	13.504	17.500	23.330	32.000	45.111	65.209	96.341	144.949	221.247
33	8.722	10.766	13.633	17.760	23.843	33.000	47.033	68.857	103.181	157.624	244.471
34	8.750	10.825	13.755	18.010	24.346	34.000	48.994	72.651	110.432	171.314	270.018
35	8.775	10.879	13.870	18.249	24.839	35.000	50.993	76.597	118.118	186.099	298.119
36	8.797	10.928	13.978	18.479	25.322	36.000	53.033	80.701	126.265	202.067	329.031
37	8.818	10.974	14.079	18.700	25.796	37.000	55.114	84.969	134.901	219.312	363.034
38	8.836	11.016	14.174	18.912	26.260	38.000	57.236	89.408	144.055	237.937	400.437
39	8.852	11.055	14.264	19.116	26.715	39.000	59.401	94.024	153.758	258.052	441.580
40	8.867	11.091	14.348	19.311	27.160	40.000	61.609	98.825	164.043	279.776	486.838
41	8.880	11.123	14.427	19.499	27.597	41.000	63.861	103.818	174.945	303.238	536.621
42	8.892	11.153	14.502	19.679	28.025	42.000	66.158	109.010	186.502	328.576	591.382
43	8.903	11.181	14.571	19.852	28.445	43.000	68.501	114.411	198.752	355.942	651.620
44	8.913	11.207	14.637	20.017	28.856	44.000	70.891	120.027	211.737	385.497	717.881
45	8.921	11.230	14.699	20.177	29.259	45.000	73.329	125.868	225.501	417.417	790.769
46	8.929	11.252	14.757	20.330	29.654	46.000	75.815	131.943	240.091	451.890	870.945
47	8.936	11.272	14.812	20.476	30.040	47.000	78.351	138.260	255.556	489.121	959.138
48	8.943	11.290	14.863	20.617	30.420	48.000	80.938	144.831	271.949	529.330	1056.151
49	8.948	11.307	14.911	20.753	30.791	49.000	83.577	151.664	289.325	572.756	1162.865
50	8.954	11.322	14.956	20.883	31.155	50.000	86.269	158.770	307.745	619.656	1280.251

"Must Cost" Estimate for Solar Systems

The Office of Management and Budget (OMB) has directed that energy conservation projects use 10% (i = 10%) in excess of long term inflation as the interest or cost of money. Such an interest rate represents a total cost of money in the 15% range (i+g = 10% + 5%). This suggests a governmental desire for the project to both pay for itself and earn money. The money is earned at a rate 7% higher than the cost of money to the U. S. Government (Long Term U.S. Treasury Bonds at 8%). If this criteria is applied to an infant technology in the development stage, it will result in long payback times. This may be counter-productive in encouraging the solar thermal system technology.

This table shows an example of the highest price (Maximum "Must Cost") that can be paid for a solar system and have it pay back by fuel savings in 25 years. If the type of energy being supplemented by solar energy is high cost, a higher cost solar system can be justified.

At the present time, the payback analysis is most dependent on the OMB decreed interest rate (i) as applied to the value of money in excess of inflation. The next factor of importance is the fuel cost and fuel growth rate (e) in excess of the general inflation. Then finally, the payback depends on the solar system cost and annual total system efficiency.

On the bottom of this table are a range of system costs per the DOE Solar Handbook. Space heating and cooling projects can run from $40 to $80 per square foot for the direct construction cost. The maximum costs allowed in the top left side of the table are not feasible now. The costs on the table's lower right side are easy to achieve. The middle range is difficult, but can be achieved.

The third column (i = 3%) is the most representative of the cost of money to the U. S. Government. This represents achievable system cost.

MAXIMUM "MUST COST" SOLAR SYSTEM - 25-YR. PAYBACK

ENERGY SUPPLEMENTED			*MAXIMUM COST $/FT²			
TYPE	COST	GROWTH RATE	OMB i = 10%	SIMPLE i = e	REALISTIC i = 3%	SIMPLE ESCALATED i = 0%
GAS	$2/MCF	10%	18 (NOT NOW FEASIBLE)	18	47	76
OIL	$.40/GAL	8%	20	25	50 (DIFFICULT)	79
ELEC. (RESISTANCE HEATING)	$.03/KW	8%	52	66	131	209
	.06/KW	5%	77	132	(EASY) 196	265

SYSTEMS COSTS (DOE HANDBOOK)	INSTALLED COST/SF_c		TOTAL COST	
	New construction	Retrofit	New Construction	Retrofit
Space heating and cooling	$35 - 65	$40 - 80	$45 - 80	$50 - 100

*50% Solar System Efficiency
600,000 BTU/ft² Solar Insolation

GRUMMAN